Intel® Low-Power Technologies

Bringing Longer Battery Life – and Higher Productivity – to Mobile Computing

Contents

Executive Summary

The notebook PC has become pervasive in corporate environments. Notebook usage by business users has increased 60 percent over the last three years[1]. Leading companies such as AT&T, Boeing, Marriott, Procter & Gamble and Intel are assigning them to more than 50 percent of their employees. And why not? Notebooks enable people to be productive at any time, anywhere in the world. They offer outstanding return on investment (ROI), plus a real competitive advantage. And performance keeps getting better, model after model, year after year.

Yes, mobile PCs are justifiably in demand today, and new advances are in the works that are likely to make them even more popular. Specifically, new technology trends such as wireless computing are gaining traction—enhancing the notebook user experience and causing battery life to become a key criterion in notebook selection. Intel is working with leading OEMs and system component manufacturers to reduce power consumption and extend battery life.

Intel's latest mobile processors, the Mobile Intel® Pentium® 4 Processor - M, Mobile Intel® Pentium® III Processor - M – and all mobile Intel® Low-Volt (LV) and Ultra-Low-Volt (ULV) processors – are designed with low-power technologies to maximize battery life and performance while enhancing the productivity of notebook computer users. Today, low-power mobile processors are more powerful and better able to handle computer-intensive applications than ever before. They are the products of more than a decade of Intel® Research and Development that has consistently delivered cutting-edge, low-power technologies and industry-leading performance. The mobile Intel® processor product line is by far the most extensive in the industry. In full-size, thin and light, and sub-notebook sectors, Intel offers processors that make it easy for notebook manufacturers to give customers the mobile PCs that suit their exact needs.

This white paper briefly examines the need for low power in mobile PC technologies, the various ways of determining power consumption, low-power technologies from Intel, and Intel-driven efforts to reduce power consumption across the entire mobile PC platform.

Long Battery Life and Productivity Go Hand in Hand

The longer you can go mobile while accessing all of your business tools and data, the more opportunity you have to be productive and efficient. Gartner Consulting estimates that companies with notebook computer users who spend 20 percent or more of their time out of the office realize a minimum annual benefit of $34,560 per user due to improved productivity and efficiency[2]. In addition, a 2001 Sage Research report based on interviews with twenty large North American companies found that users gained an additional eight hours per week of time-savings by making the most of mobile PCs in a corporate wireless LAN setting[3].

Today, the benefits of mobility go beyond the traditional road-warrior scenario to all business professionals. Mobile PCs enable employees to be productive not only in the office, but at home, while commuting, at conferences, client sites, and so on. Many leading companies are actively promoting this new type of productivity by providing mobile PCs to the majority of their employees.

Power Requirements of the Mobile PC Platform

It doesn't pay to have insulation in the walls of a house but not in the roof. So it is with power management in notebooks: the subsystems must be power-optimized across the entire mobile PC platform. Intel's Mobile Architecture Group developed power analysis tools and made the fundamental discovery that system components other than the mobile processor represent 80 to 90 percent of platform power consumption, and are the primary reason for mobile system power inefficiency. Power usage under the Ziff Davis BatteryMark* 4.0.1 benchmark and Windows* Idle is dominated by LCD (about 30%), Chipset (about 15%), Graphics Controller (about 8%), Hard-Disk Drive (about 7%) and Power Supply loss (about 10%). The Processor power is about 10% under Ziff Davis BatteryMark* 4.0.1 and only about 3% under Windows Idle. (See charts on page 5.)

What's especially interesting is that processor power scales by about four times going from idle to active, whereas other subsystems (LCD, HDD, etc.) remain virtually unchanged whether in idle or active states. It is important that all subsystems do *nothing* very efficiently. This will ensure that the system offers optimum battery life when it is actually doing *something.*

Intel is working with the industry to reduce power consumption in all mobile PC components in order to maximize low-power benefits for the entire system.

The Low-Power Leaders: Mobile Intel® Pentium® 4 Processor - M and Mobile Intel® Pentium® III Processor - M

Intel offers two advanced mobile processor families to span all mobile computing needs. The Mobile Intel® Pentium® 4 Processor - M is designed for full-size as well as thin and light systems. The Mobile Intel® Pentium® III Processor - M is designed for all form factors: full-size, thin and light, mini-, sub- and tablet mobile PCs. Both "M" families feature the following low-power technologies (except where otherwise noted):

Enhanced Intel® SpeedStep® Technology

Enhanced Intel® SpeedStep® technology allows users to maximize battery life by enabling real-time, dynamic switching of voltage and frequency based on system power source (i.e., battery or AC), thermal environment, user preferences, and CPU demand:

- Maximum Performance Mode – the default mode, when connected to an AC power source, sets the CPU at the highest speed for the best performance.
- Automatic Mode – the default mode, when the system is running on battery, allows the system software to measure CPU utilization and set the CPU frequency and voltage based on demand, achieving the optimal balance between power and performance. (The system will also default to this mode or Battery-Optimized Performance Mode when CPU temperature rises above a given level set in the BIOS.)
- Battery-Optimized Performance Mode – set via system software (Windows XP*) or user preference (Windows* 9x, Windows 2000) reduces the processor speed and voltage to minimum levels to significantly reduce power while running the processor at a nominal frequency fit for many tasks (DVD, office applications, etc.).
- Maximum Battery Mode – also set via system software (Windows XP) or user preference (Windows 9x, Windows 2000), it reduces the power consumption of the CPU even more by adjusting the CPU clock downward when there is a significant load on the microprocessor. Maximum Battery mode is designed for occasions when the user has the greatest need for long battery life and therefore is willing to make some compromises in performance.

The automatic switching between performance modes is invisible to users because it takes place in less than 1/1000 of a second, without any interruption to the applications currently running. If they wish, users can also manually switch between the four performance modes through the Enhanced Intel SpeedStep technology icon on the Windows taskbar in Windows 9x and Windows 2000. On Windows XP, users can indirectly change the performance state of the processor based on their settings in the power management control panel icon. The policy is also influenced by the platform ACPI implementation, as well as the current power source of the platform (AC/battery).

Intel recognizes the necessity to reduce power across the board and is working with subsystem vendors to optimize hardware/drivers and improve their efficiency during idle time and under all power-usage conditions.

Intel's Most Advanced Processors for Mobile Computing

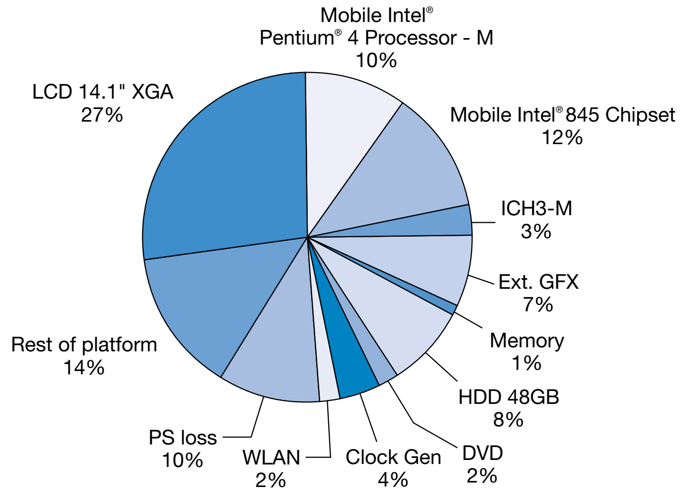
Mobile Intel® Pentium® III Processor - M:

- Delivers mainstream performance enabled by the 0.13 micron process, larger 512KB L2 cache, and 133MHz bus. Low-power features, including Deeper Sleep and support for Enhanced Intel® SpeedStep® technology, enable outstanding battery life.
- Intel® hub architecture, and AGP-4X external graphics or DirectAGP integrated graphics offer best-in-class I/O performance, while the low-power modes of the Intel® 830 Chipset increase battery life even further.

Mobile Intel® Pentium® 4 Processor - M:

- Delivers outstanding performance through Intel® NetBurst™ architecture 400MHz bus and DDR memory. Power-saving features, including Deeper Sleep and support for Enhanced Intel® SpeedStep® technology, enable long battery life.
- Paired with the Mobile Intel® 845 Chipset, outstanding mobile platform performance and long battery life are delivered through Intel® hub architecture, flexible external AGP graphics and advanced mobile power-management features such as bandwidth management for DDR memory and mobile clock manager.

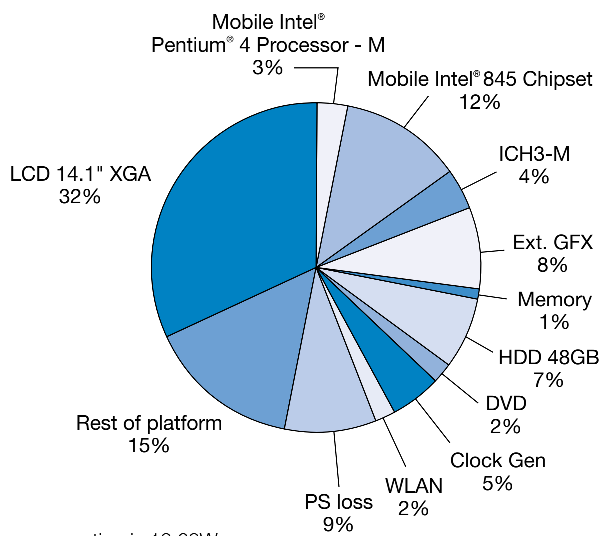
Ziff Davis BatteryMark* 4.0.1 Benchmark



System power consumption is 15.52W

The average power consumed by each subsystem in a full-size notebook PC during a full run of the Ziff Davis BatteryMark* 4.0.1 (battery life benchmark). Source: Intel® Mobile Products Group, Q1 2002.

Windows* Idle



System power consumption is 13.68W

The average power consumed by each subsystem in a full-size notebook PC when Windows* is idle. Source: Intel® Mobile Products Group, Q1 2002.

Deeper Sleep Alert State

Also known as the C4 ACPI state, the Deeper Sleep Alert State is a dynamic power-management mode that reduces average power consumption by taking the processor into the lowest power state that can be achieved while maintaining its context. The processor transitions to the Deeper Sleep Alert State when the voltage regulator lowers the core voltage, based on signals from the I/O controller hub. This allows operating system and software vendors to offer control over the feature for the best combination of power savings and platform availability.

Like the Deep Sleep Alert State technology that preceded it, Deeper Sleep Alert State is enabled between keystrokes or in other instances when there is less than a millisecond of inactivity, and does not affect performance. It quickly restores the CPU to an active state as soon as the user resumes use of the PC. Deeper Sleep Alert State reduces processor voltage below the minimum operating voltage while preserving the processor state. It is functionally identical to the Deep Sleep Alert State but at 30 percent lower power.

Low-Voltage and Ultra-Low-Voltage Processors

In addition to the Mobile Intel Pentium 4 Processor - M and Mobile Intel Pentium III Processor - M models, Intel offers Low-Voltage (LV) and Ultra-Low-Voltage (ULV) Mobile Intel Pentium III Processor - M options. Mobile Intel® processors with the LV and ULV designations bring Intel performance and extended battery life to a new class of super-thin and light mini-notebooks and sub-notebooks, as well as tablet PCs.

In Battery-Optimized Performance mode, the Low-Voltage Pentium III Processor - M uses less than a watt in average power. The ULV version of the processor uses less than 0.5 watt of average power in Battery-Optimized Performance mode[4].

0.13 Micron Process Technology

Like the latest Pentium 4 processors for the desktop, the Mobile Intel Pentium 4 Processors - M are built on the semiconductor industry's most advanced manufacturing technology, Intel's 0.13 micron fabrication process. Using this

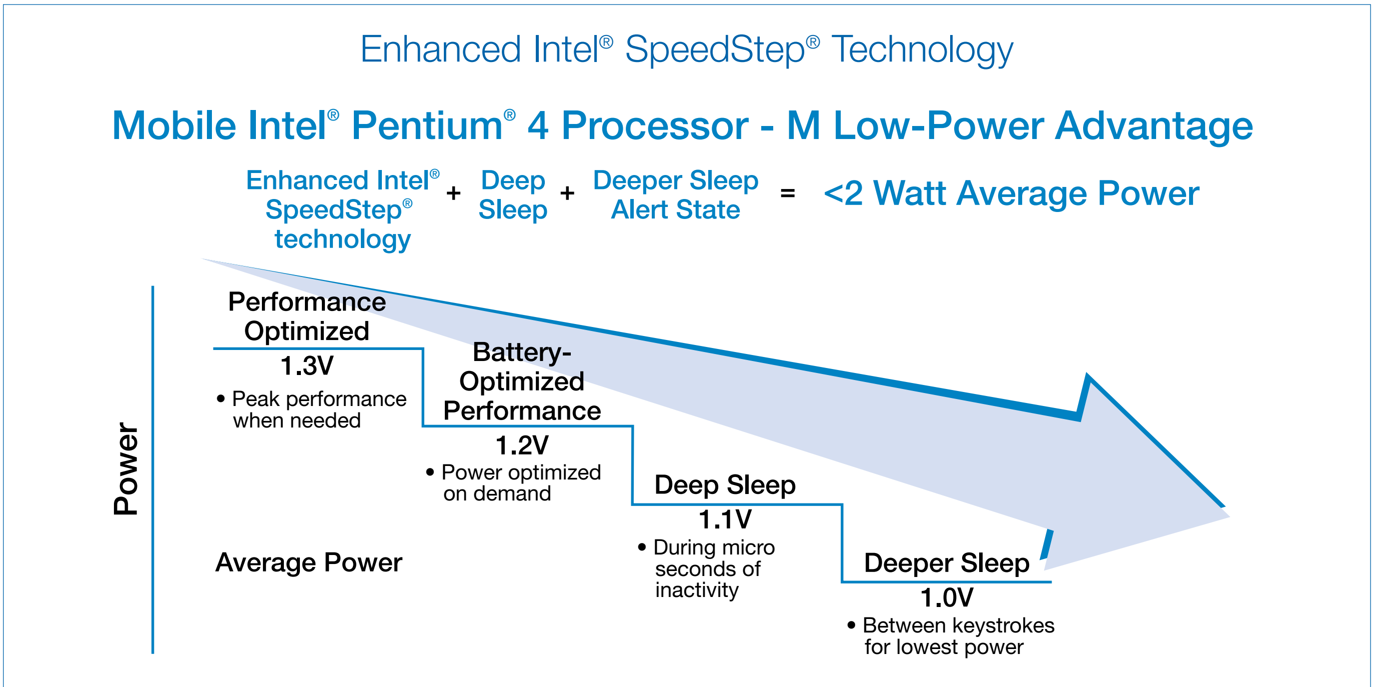


Figure 1. In tests conducted using a Mobile Intel® Pentium® 4 Processor - M-based notebook PC at 1.70 GHz, Intel® low-power technologies work together to drive processor power usage below 2 watts on average.[5]

technology, Intel was able to increase the chip's on-board memory (called level two cache) while reducing overall processor size by over 30 percent. With Intel's 0.13 micron process technology, which uses highly efficient copper interconnects, it is possible to build circuits so small that 55 million transistors can be placed on each chip. It would take almost 1000 of these "wires" placed side-by-side to equal the width of a human hair.

Specifically, 0.13 micron technology refers to the feature size of the poly-silicon gate in the microprocessor. This feature size has a direct correlation to the speed and power requirements of the microprocessor. As feature sizes are reduced, the process speed (MHz or GHz) increases while the power requirements decrease correspondingly. 0.13 micron is currently the smallest feature size available in high-volume semiconductor manufacturing. This technology allows for greater speeds than ever before with lower power consumption, resulting in greater performance and extended battery life in thinner, lighter notebooks.

Intel® Mobile Voltage Positioning

Designed specifically for mobile Intel processors, Intel® Mobile Voltage Positioning (IMVP) is a smart voltage regulation technology that dynamically reduces core voltage with increases in current, thereby maintaining high performance while lowering power consumption, including the power requirements for Deep Sleep and Deeper Sleep Alert States.

IMVP also has a beneficial effect on thermal design power (TDP), which is a measure of the heat generated as power is consumed while the processor is running a worst-case application. TDP must be kept within certain limits to ensure system reliability without resorting to power-hungry, noise-generating cooling systems. A reduced TDP enables notebook designers to put higher performance processors into thinner and lighter notebooks.

Intel recently introduced IMVP-III, a substantially improved version of the original IMVP technology that is supported by the Mobile Intel Pentium 4 Processor - M. IMVP-III uses several innovative techniques to reduce power requirements and TDP. Several vendors are offering solutions that incorporate IMVP-III, and you can expect to see this technology become a popular feature in many high-performance notebooks.

Intel's Low-Power Mobile Chipsets

Intel's low-power technologies extend to the chipsets that support the processor and direct data traffic throughout the mobile PC platform. When the Mobile Intel Pentium III Processor - M and Mobile Intel Pentium 4 Processor - M are combined with chipsets from the Intel® 830 and Mobile Intel® 845 Chipset families, respectively, mobile PCs can achieve significant platform power savings. That's because low-power technologies such as Enhanced Intel SpeedStep technology, Deeper Sleep Alert State and IMVP-III are supported by the combination of mobile Intel processors and chipsets.

Chipset-Level Power Management

The Intel 830 and 845 families of chipsets also offer the latest in power-management technologies, including:

- Support for the ACPI (Advanced Configuration and Power Interface) 2.0 specification, which ensures that developers can continue to provide new power-management technologies in both hardware and operating systems, while ensuring that these technologies always work together properly.
- Support for APM (Advanced Power Management) 1.2, which defines normal and low-power states in a common way so that software can be written to take best advantage of them.
- Mobile Clock Manager, which controls chipset clock speeds to reduce chipset power during periods of low activity, further extending battery life.
- Low-Power Chipset Modes, providing system-wide power savings through techniques such as dynamic clockgating, dynamic buffer power-down, memory power-management control and more.
- Power management for AGP graphics provides efficient use of system main memory for graphics rendering, resulting in high-performance graphics and longer battery life.

Low-Power Efforts Across the Platform

As you can see, Intel is using the most advanced techniques to minimize power usage while maximizing performance across all the Intel® components that go into the mobile platform. But there are many other components that support Intel processors and chipsets to make up a complete mobile PC. That's why Intel is driving industry efforts to reduce power consumption across the platform, including:

- Optimizing the voltage regulator to improve the efficiency with which battery power is converted for use by the system.
- Improving power partitioning by removing extra voltage translators in the system, thereby reducing power wastage. For example, circumventing the need for a 5v to 3.3v converter inside the hard drive by using the 3.3v directly from the motherboard.
- Optimizing the backlight inverter to extend the dimming range, set brightness automatically according to ambient light, eliminate the need to over-power the LCD to compensate for low-voltage conditions, and eliminate unnecessary power dissipation due to line regulation.
- Optimizing battery loading by incorporating technologies that reduce large fluctuations in battery voltage, which can shorten battery life and even lead to premature system shut-down.
- Implementing device performance states in operating systems, drivers and other software to provide the most advantageous trade-off between system performance and power savings.
- Optimizing "always-on" subsystems, such as ports that require automatic discovery or removable-media readers that must detect disk insertion/removal, to minimize power consumption when they're needed and even allow disabling when they're not.
- Power-Management tool development to help OEMs evaluate if a specific subsystem is properly power managed.

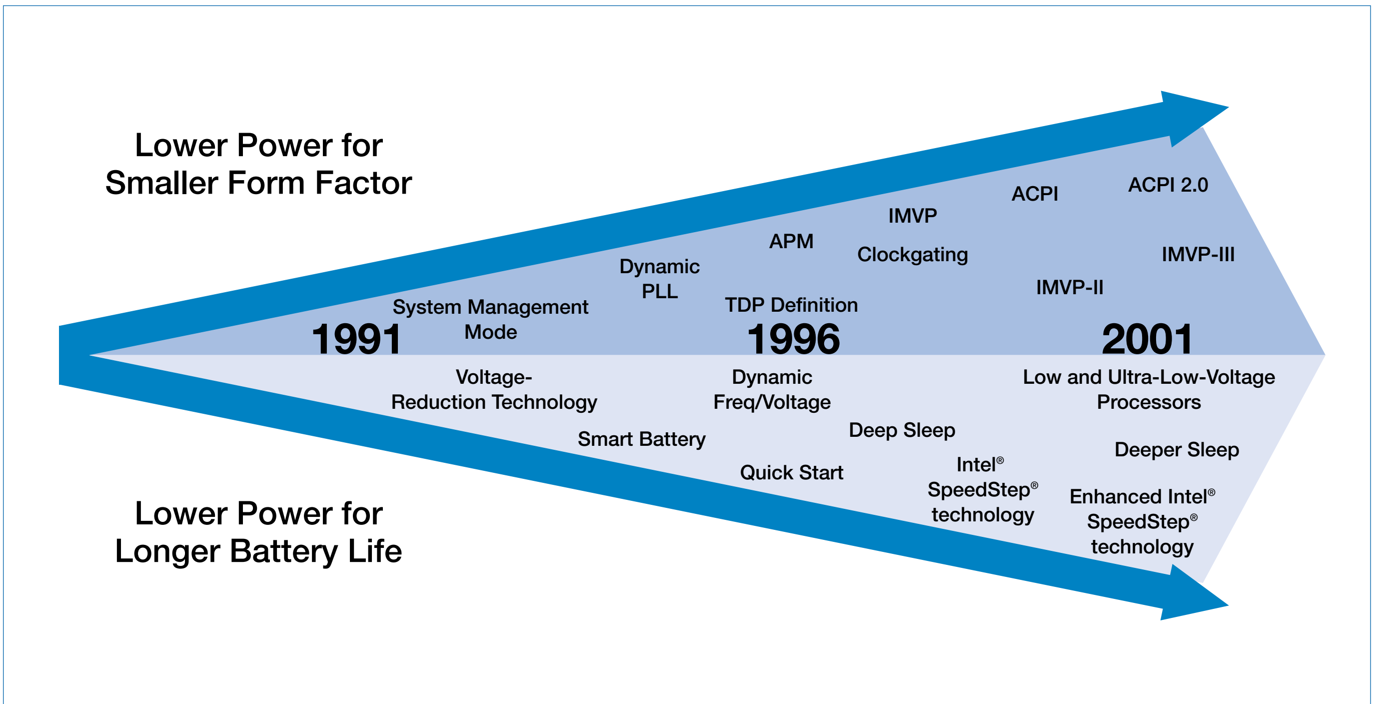


Figure 2. For over a decade, Intel has introduced the most advanced low-power technologies to enable smaller mobile PCs and longer battery life.

Intel's preliminary testing has shown that an approximately 15 to 30 percent extension in battery life can be achieved when techniques like these are used on mobile PC platforms based on Intel® mobile processors. And Intel is working with product designers and manufacturers throughout the mobile PC industry to ensure that the mobile systems of today and tomorrow take advantage of these techniques and others to provide the best performance at the lowest power possible.

Low-Power Innovation – Yesterday, Today and Tomorrow

Along with ongoing improvements in performance, power-management innovations across the entire mobile system platform are helping to make mobile PCs an essential tool for traveling professionals, and an excellent way to increase the independence and productivity of virtually any knowledge worker.

For over a decade, Intel has led the way with low-power technologies that advance the mobile PC platform in two directions – higher performance and longer battery life.

These innovations give IT managers and business professionals a wealth of choice for the highest performance and lowest power consumption in each segment. Whether you choose a full-sized system, a sub-notebook or a tablet PC – Intel mobile processors, chipsets and industry efforts ensure that your battery power is always managed to squeeze the most computing value from every electron.

For the best low-power technologies Intel has to offer, look for the "M." Mobile PCs containing the Mobile Intel Pentium III Processor - M and Mobile Intel Pentium 4 Processor - M offer higher performance, longer battery life, thinner form factors and cooler temperatures – all leading to higher productivity. As more people and businesses go mobile, look to Intel for fresh innovations that will continue to revolutionize mobile computing in the years to come.

Evaluating Low-Power Mobile Processors

Assessing processor performance and how it relates to power usage can be problematic because of all the variables inherent in the process. Applications and system components add their own burdens and can alter results. System configuration must therefore be standardized, and tests must be defined by processor power states. Two types of power are used to evaluate processors:

- Average power of an Intel® mobile processor is the power consumed during the operation of the processor in Battery-Optimized Performance mode of the industry-standard benchmark, Ziff Davis BatteryMark* 4.0.1. This value is called average due to the nature of the benchmark – approximately speaking, Ziff Davis BatteryMark 4.0.1 is designed to reflect the usage pattern of today's typical notebook user.
- Thermal Design Power (TDP) is the measure of power dissipation based on sustained power under normal operating conditions including Vcc (nom load line) and max junction temperature while executing real, worst-case power applications. If the thermal solutions are designed to dissipate this level of power, then the CPU will not throttle under any real application. However, a feedback fail-safe mechanism needs to be incorporated to keep the product temperature in spec in the event of unusually strenuous usage such as a computer virus.

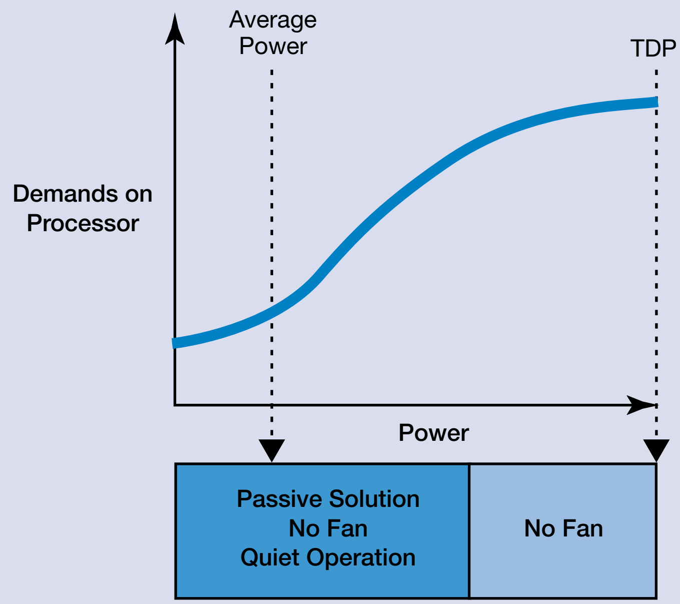


Figure 3. The processing demands of typical office applications determine Average and Thermal Design Power (TDP). Deeper Sleep Alert State, which isn't illustrated, uses even less power. When running typical office applications using Average power, mobile Intel® processors can typically run without using a cooling fan. Power is saved, battery life is extended and the notebook is quieter.

DISCLAIMER: The average power data represents single-unit data. Power measurements are generally taken by running certain performance and/or battery-life benchmarks on a specific computer system. Different measurements can be designed to approximate the various power characteristics of a component such as a processor, or of a computer system. Some of the often-measured power characteristics include thermal design power (or TDP) and average power. Examples of benchmarks used to measure power include: Ziff-Davis BatteryMark* 4.0.1. Each processor's or system's power characteristics is measured using a particular computer system with specific hardware and software configuration. Such processors or computer systems may or may not be commercially available at the time when the measurements are taken but reasonable effort is made to make such measurements on processors and computer systems currently or soon-to-be commercially available. Where non-commercial systems are utilized for power measurements due to special instrumentation needs, reasonable effort is made to ensure that such non-commercial systems have characteristics, configurations, and properties similar to those of a computer system currently or soon-to-be commercially available, although such similarity cannot be guaranteed. Because power results are highly dependent on leakage current of the specific component under measurement and the leakage currents tend to vary from component to component within the same product family, reasonable effort is made to measure or extrapolate the power results for a component of typical leakage current. Actual power-measurement results may vary depending on the leakage current of the specific component under measurement, the definition of typical leakage current, the extrapolation methodology employed in computing the power results for a component with typical leakage current, on specific hardware and software configuration of the computer system measured, the power characteristics of those computer components not under direct measurement, variation in processor manufacturing processes, the benchmark utilized, the specific ambient condition under which the measurement is taken, and on other factors. In addition, power-measurements results are not intended to be used for predicting power results for any future component or products. Buyers should consult other sources of information to evaluate the power characteristics of the systems they are considering purchasing. For more information about power characteristics (such as TDP or average power), and a description of the systems and microprocessors used in the power measurements, and any other information about processor and system performance and power benchmarks, visit Intel's World Wide Web site at http://developer.intel.com/design/mobile/perfbref/ and follow the appropriate links.

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[1] Gartner Dataquest, May 2001.

[2] Source: Gartner Consulting, "White Paper: Benefits and TCO of Notebook Computing," July 19, 2001. Hours saved from increased productivity and efficiency were converted to annual dollar benefit using a $38 burdened salary rate for Sales Force-wired, Professional-wired and Wireless; $80 per hour for Executive-wired. These results reflect best practices by the users interviewed. Gartner expects these results to vary based on specific business conditions, infrastructure, and other operational factors.

[3] "Wireless LANs: Improving Productivity and Quality of Life," May 2001, Sage Research.

[4] Average power data represents single-unit data. The LV Pentium® III Processor - M power readings were measured on an Intel® 830M Customer Reference Board (serial number 00476) with the following configurations: Mobile Intel® LV Pentium® III Processor - M at 866/533MHz with IST technology (serial number 35126119D1452), 128MB SDRAM, System Memory 640KB, Extend RAM 32MB, Cache RAM 512KB, integrated UMA graphics, 15" external CRT monitor, Toshiba MK2017GAP* SN 61C21756G hard-disk drive, PhoenixBIOS* 4.0, Release 6.0 MPG-PDO 830M BIOS Version 0.67, Windows* 2000 operating system, ACPI enabled. The measurements were taken with the processor temperature controlled to 50 degrees C.

Average power data represents single-unit data. The ULV Pentium III Processor - M power readings were measured on an Intel® 830M Customer Reference Board (serial number 00476) with the following configurations: Mobile Intel® ULV Pentium® III Processor - M at 733/400MHz with IST technology (serial number 35126119D1452), 128MB SDRAM, System Memory 640KB, Extend RAM 32MB, Cache RAM 512KB, integrated UMA graphics, 15" external CRT monitor, Toshiba MK2017GAP* SN 61C21756G hard-disk drive, PhoenixBIOS* 4.0, Release 6.0 MPG-PDO 830M BIOS Version 0.67, Windows* 2000 operating system, ACPI enabled. The measurements were taken with the processor temperature controlled to 50 degrees C.

[5] Average power data represents single-unit data. The LV Pentium III Processor - M power readings were measured on an Intel® 830M Customer Reference Board (serial number 00476) with the following configurations: Mobile Intel® LV Pentium® III Processor - M at 866/533MHz with IST technology (serial number 35126119D1452), 128MB SDRAM, System Memory 640KB, Extend RAM 32MB, Cache RAM 512KB, integrated UMA graphics, 15" external CRT monitor, Toshiba MK2017GAP* SN 61C21756G hard-disk drive, PhoenixBIOS* 4.0, Release 6.0 MPG-PDO 830M BIOS Version 0.67, Windows* 2000 operating system, ACPI enabled. The measurements were taken with the processor temperature controlled to 50 degrees C.

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